



Single Photon Detection of 1.5THz Radiation with the Quantum Capacitance Detector

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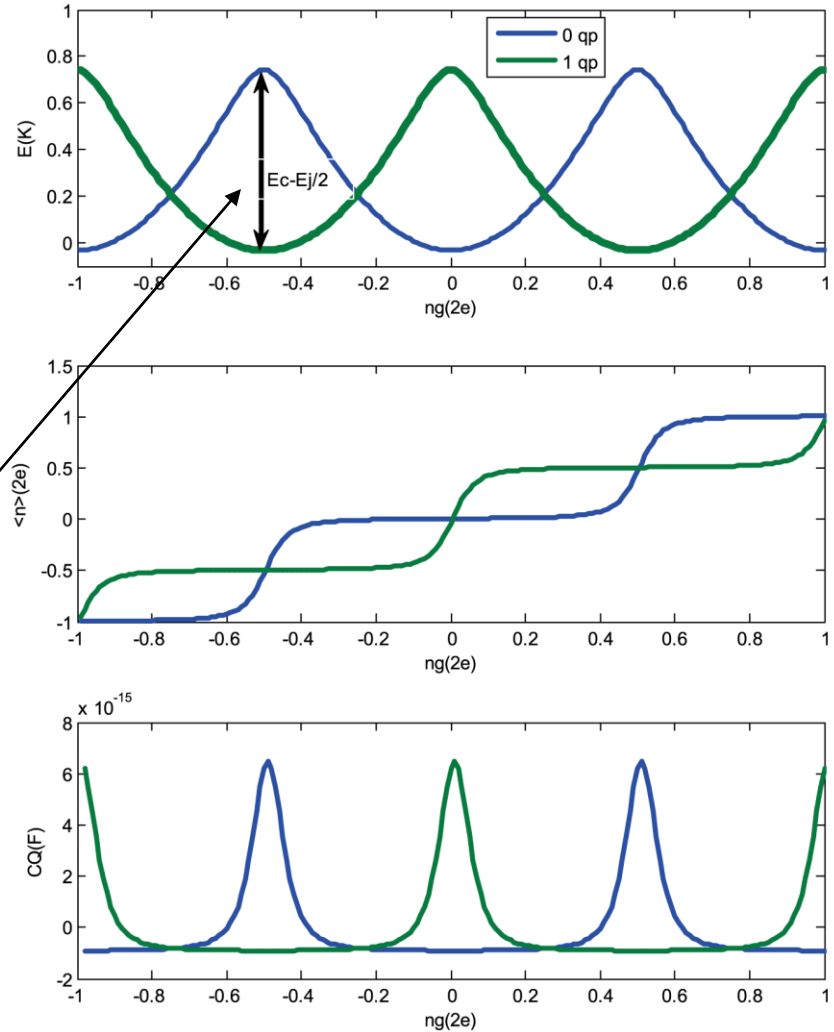
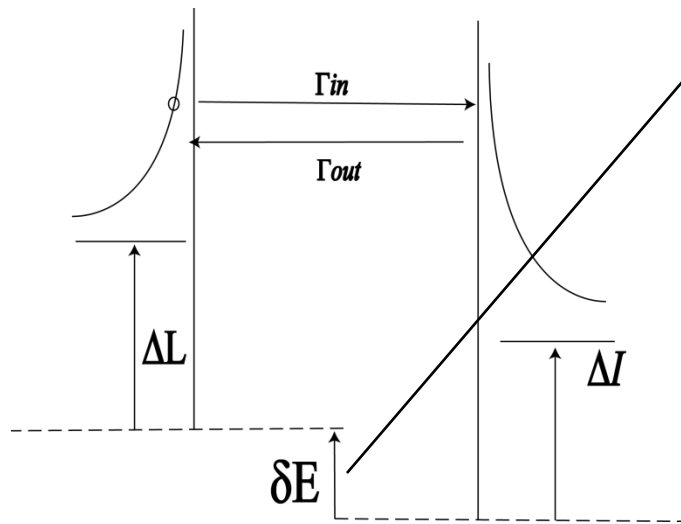
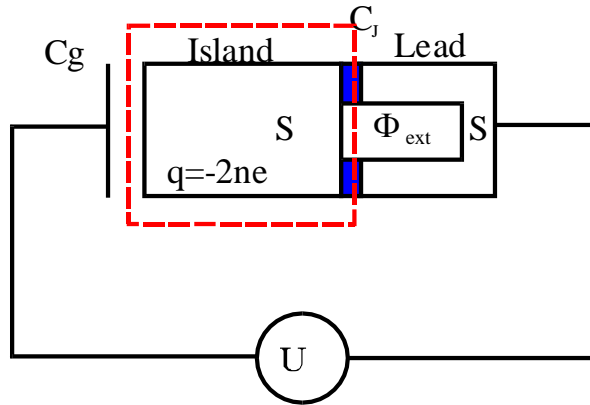
Electron Beam Lithography by Richard E.Muller

Fresnel lens array by Daniel Wilson

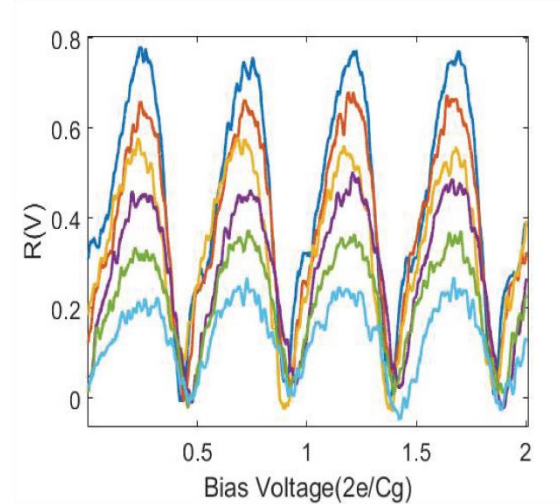
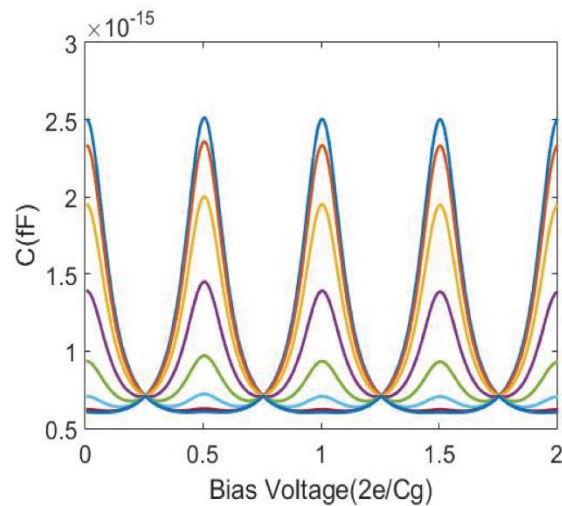
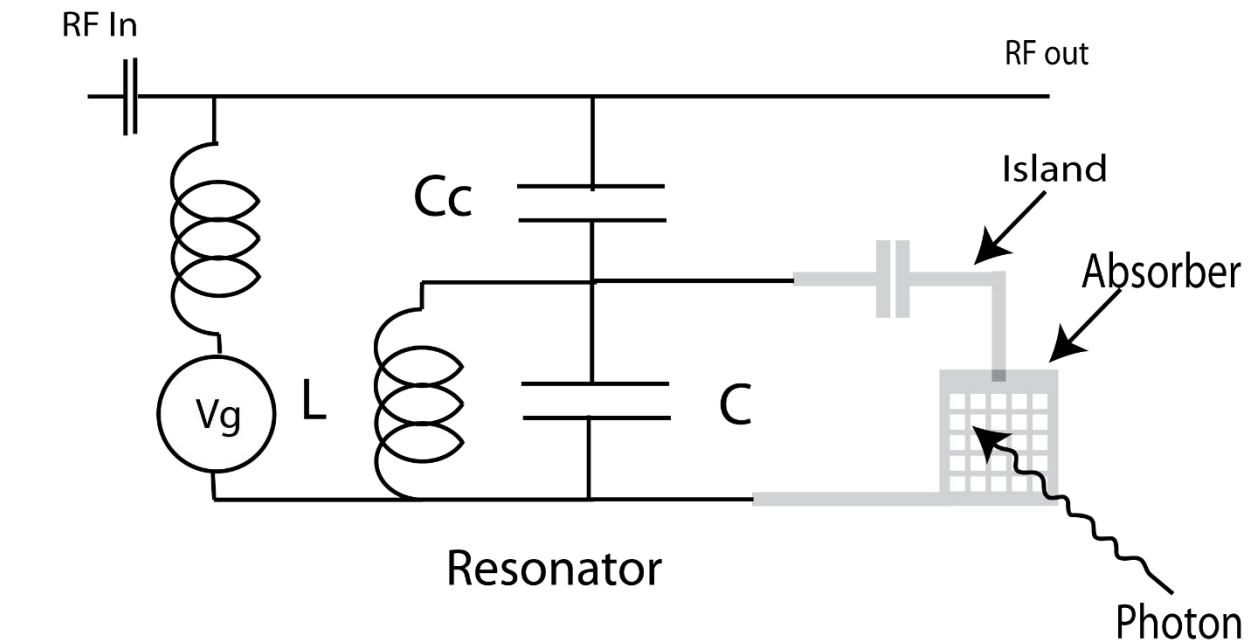
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Single Cooper-pair Box (SCB)



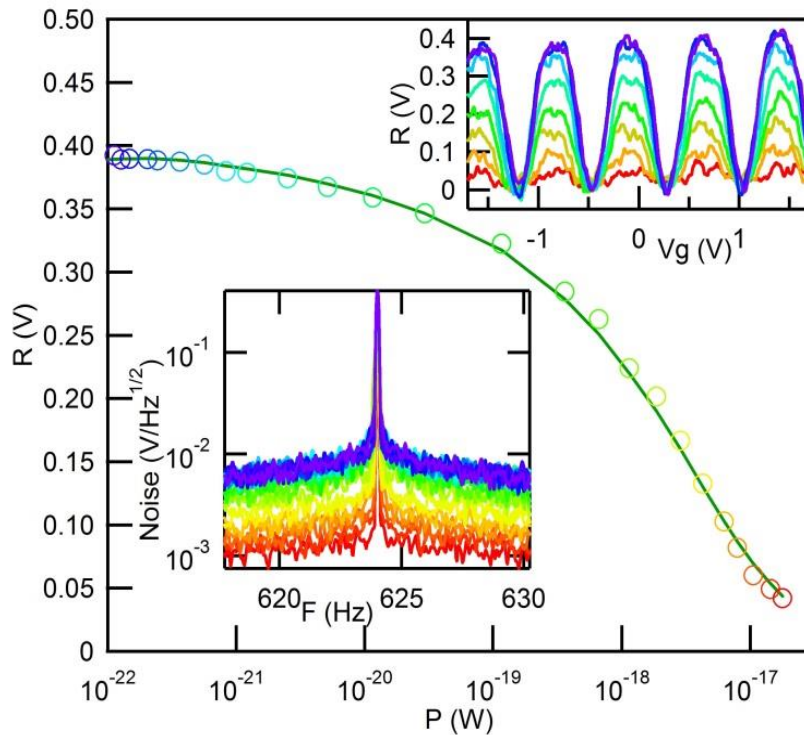
Quantum Capacitance Detector



The Quantum Capacitance Detector

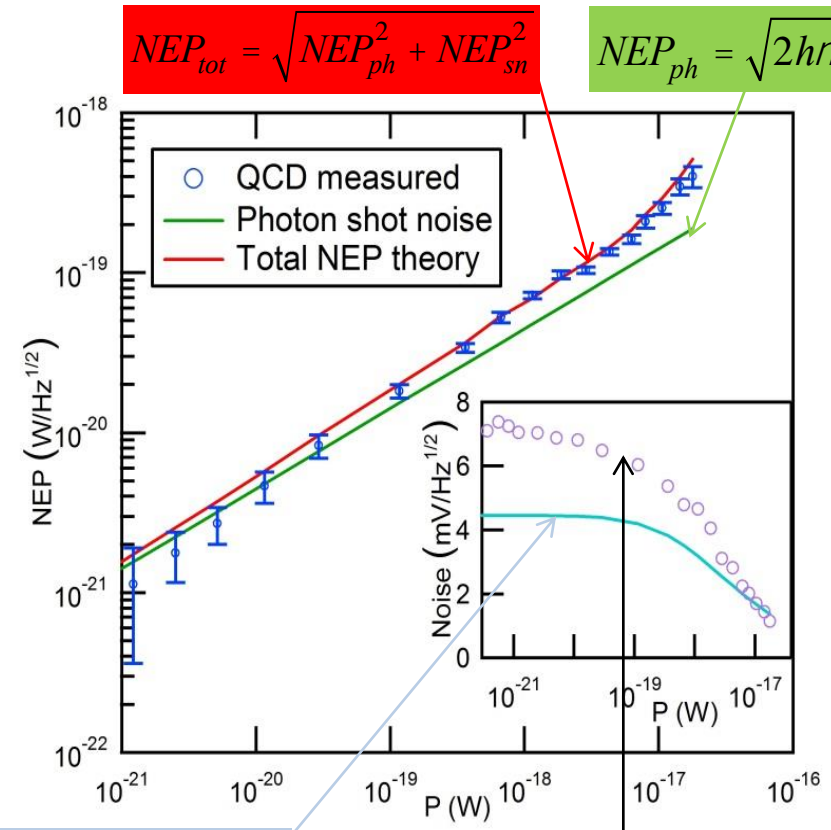
NEP as a function of optical signal
Photon shot noise limited!

Response and noise as a function of optical signal



Shot noise of electron tunneling

$$S_{sn}(f) = \sqrt{2A^2 (\Gamma_{in} \Gamma_{out} / \Gamma_{\Sigma}) / (\Gamma_{\Sigma}^2 + (2\pi f)^2)}$$



Total measured noise

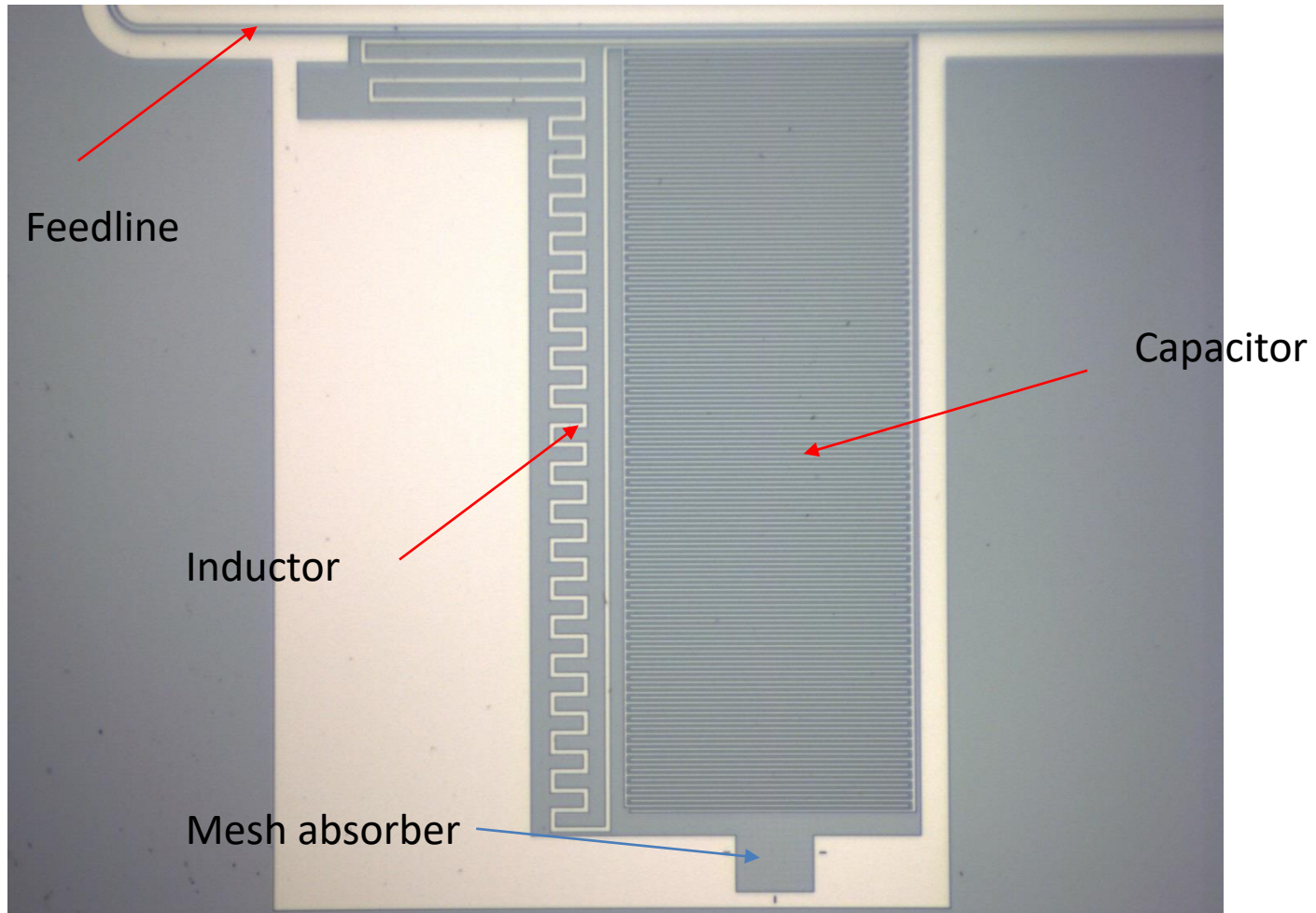
$$NEP_{SN} = S_{SN}(f) / \left(\frac{dR}{dP} \right)$$

$$NEP_{tot} = \sqrt{NEP_{ph}^2 + NEP_{sn}^2}$$

$$NEP_{ph} = \sqrt{2\hbar n P_s}$$

Lens coupled mesh absorber LEQCD

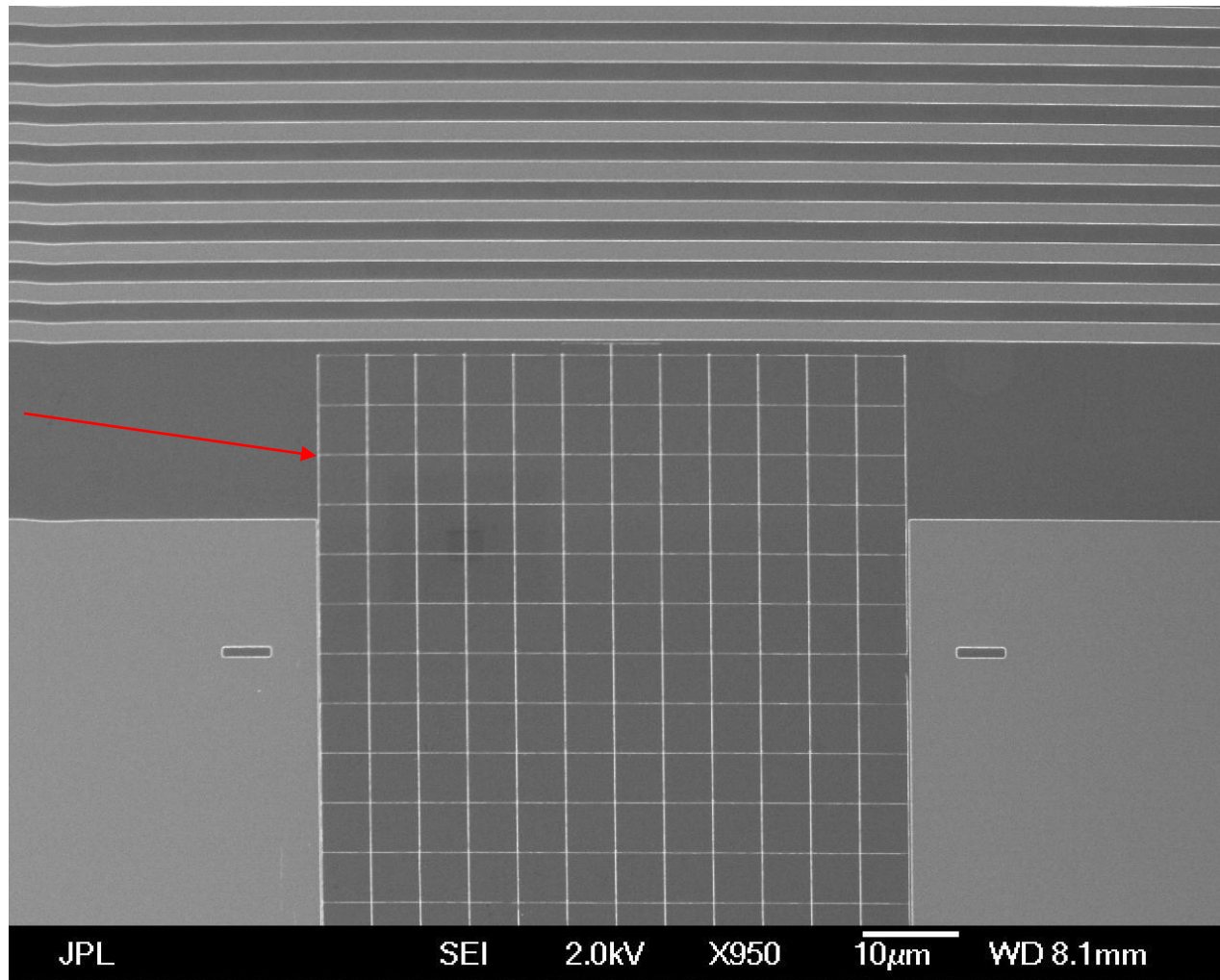
- Need mesh absorber instead of antenna to better couple to spectrometer modes
- Lumped element resonator saves space and has better characteristics than CPW half wave resonator





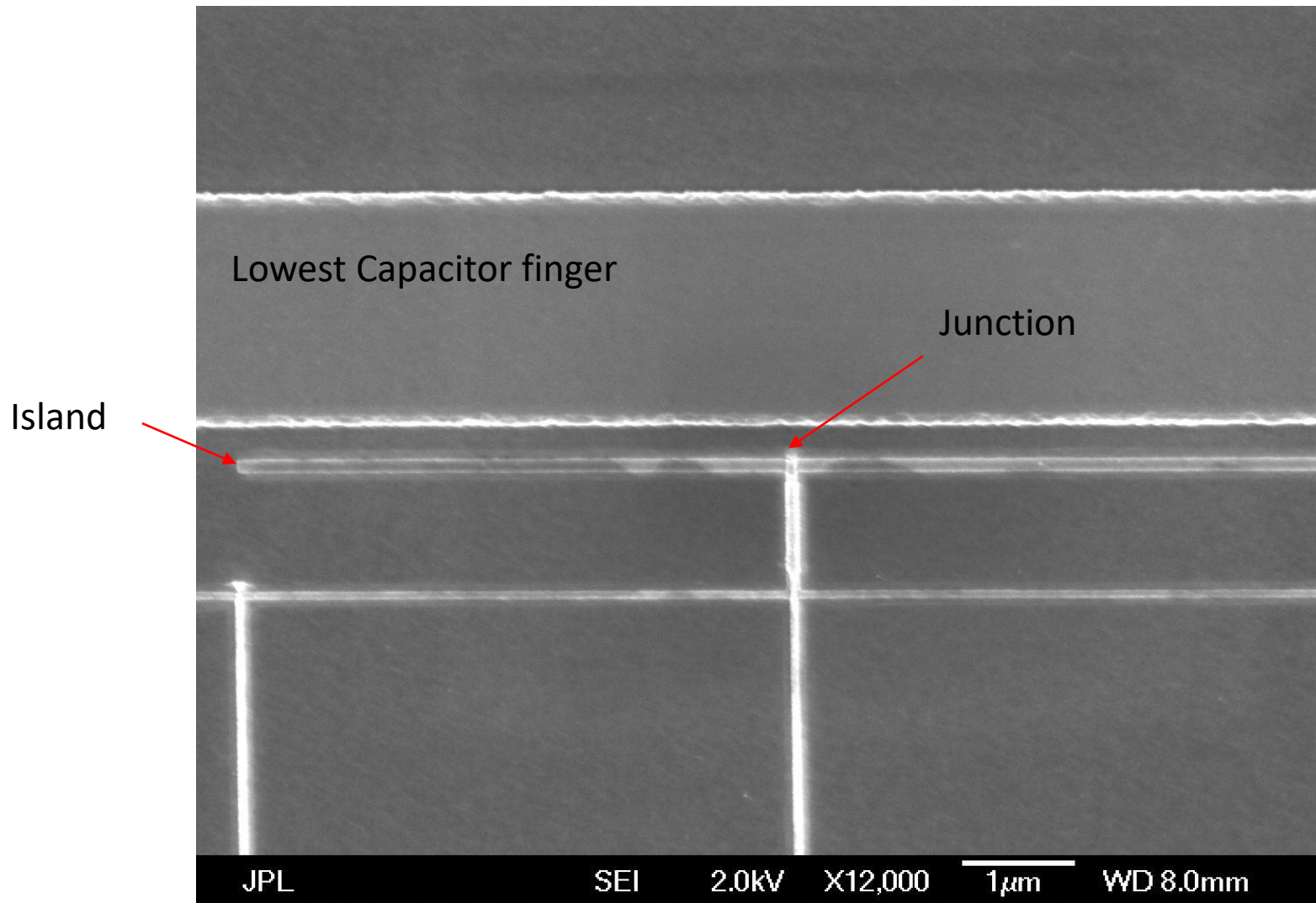
Lens coupled mesh absorber LEQCD

Mesh
absorber



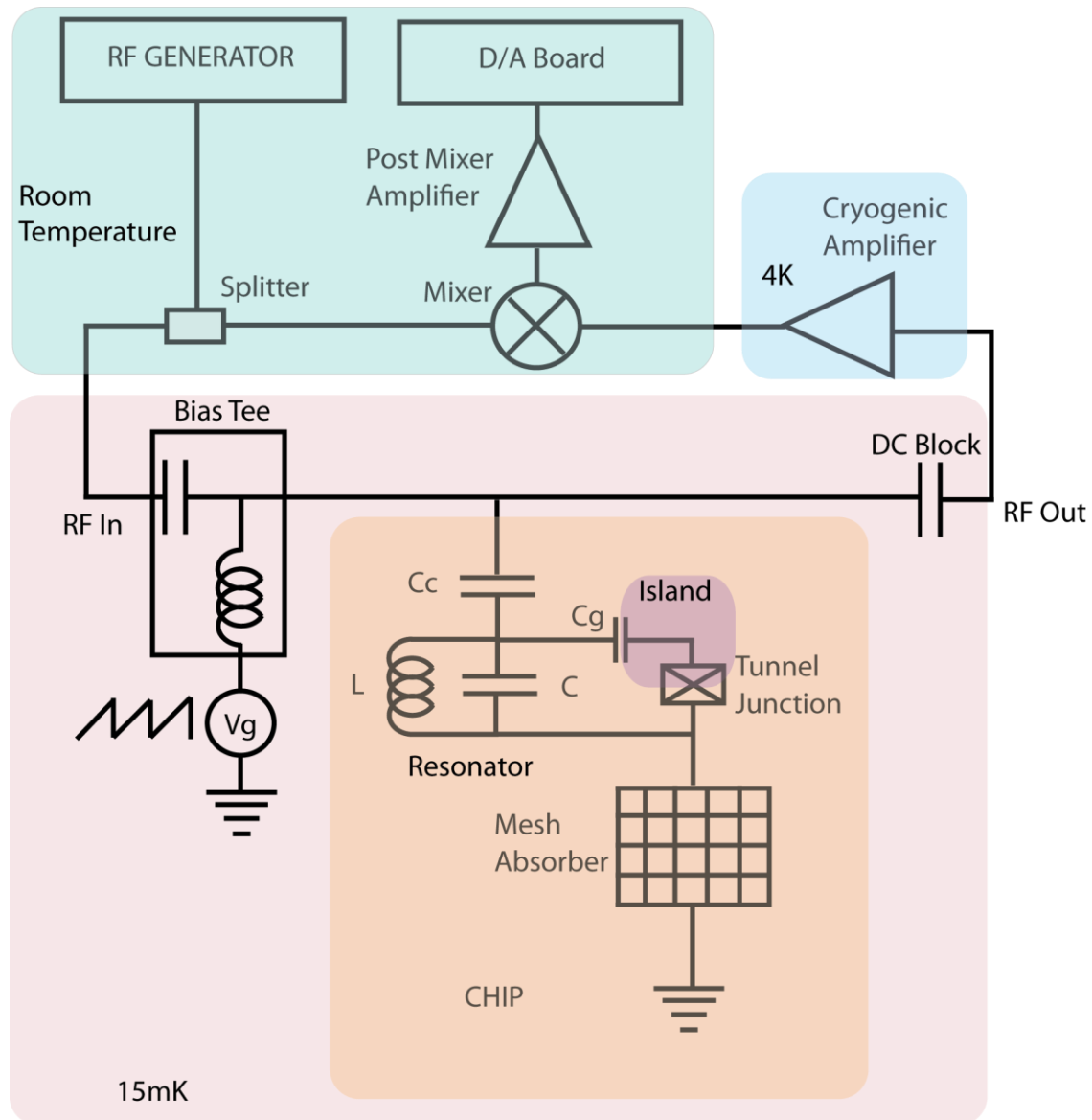


Lens coupled mesh absorber LEQCD

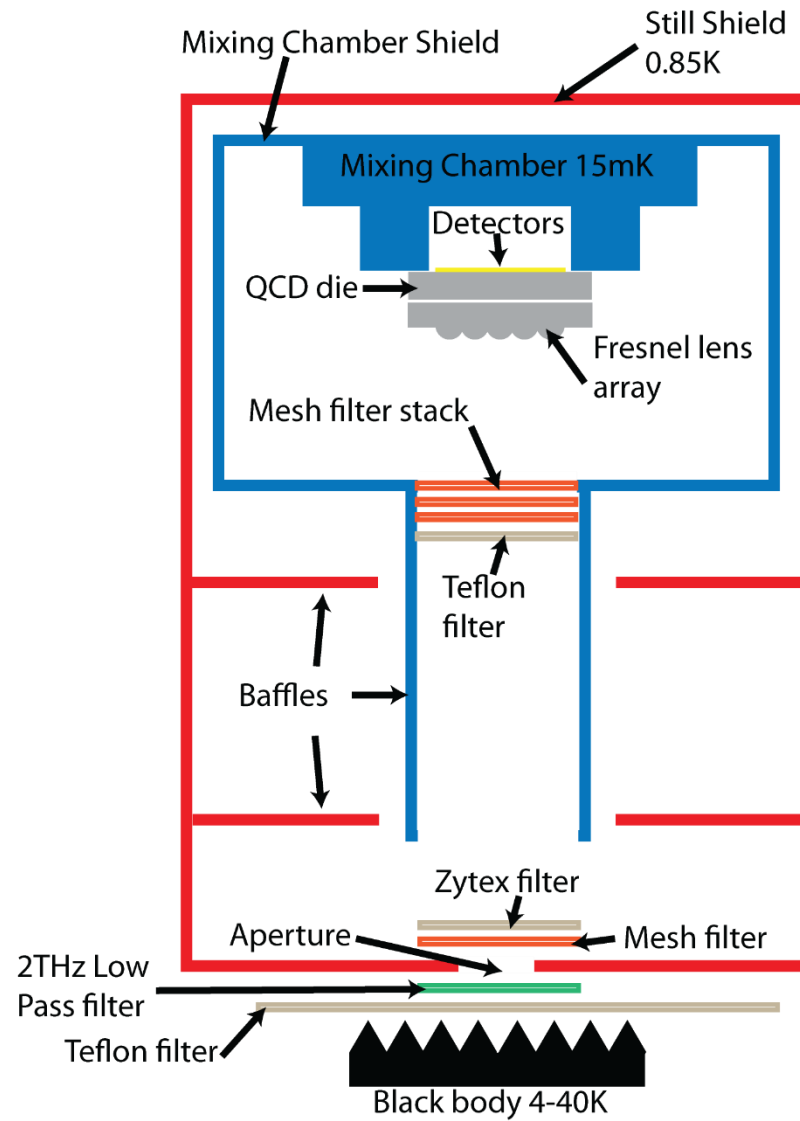




Measurement setup



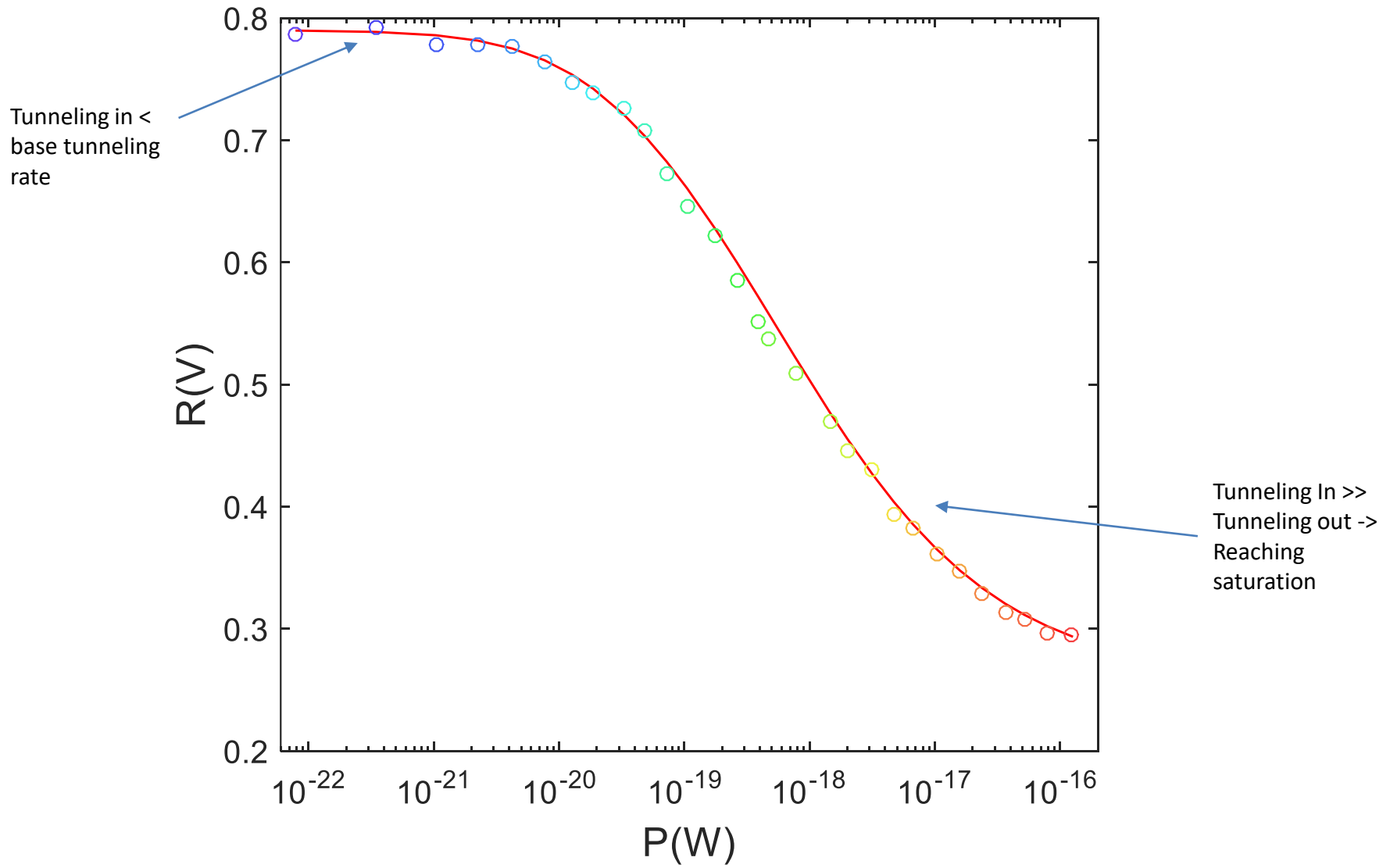
Measurement setup





Lens coupled mesh absorber LEQCD

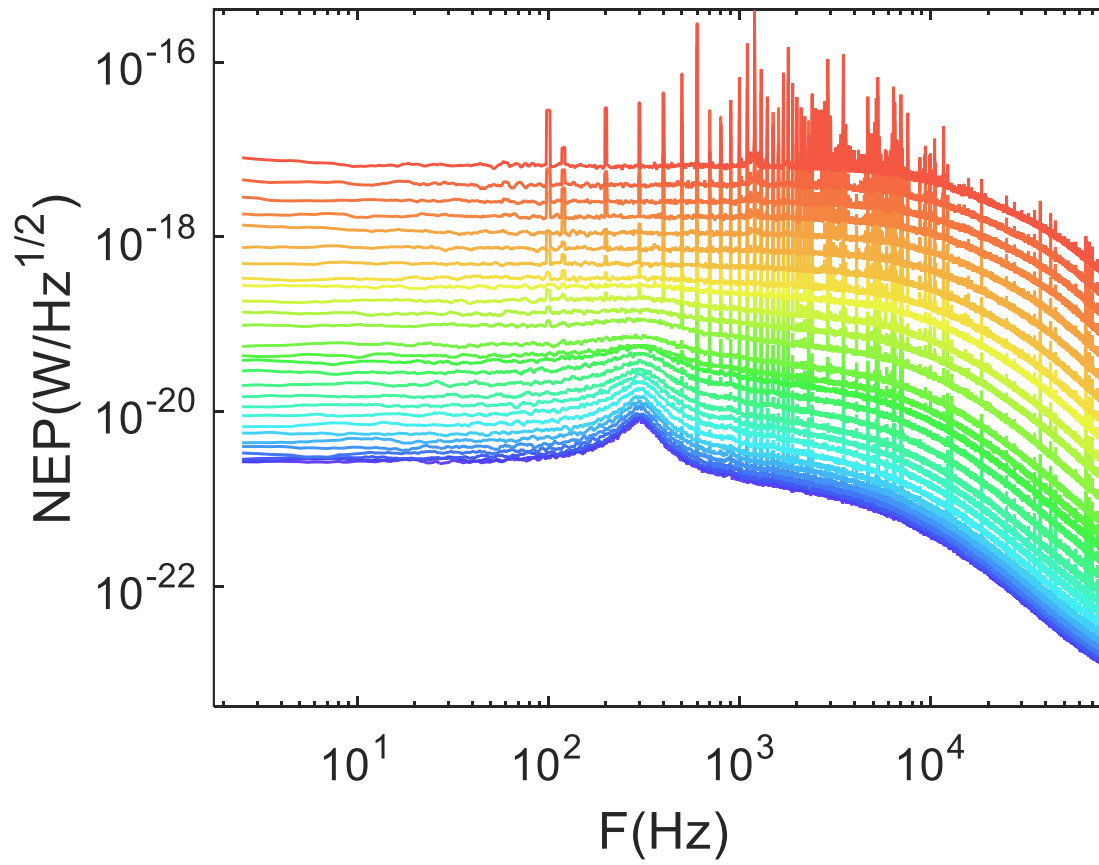
- QCD response as a function of optical power





Lens coupled mesh absorber LEQCD

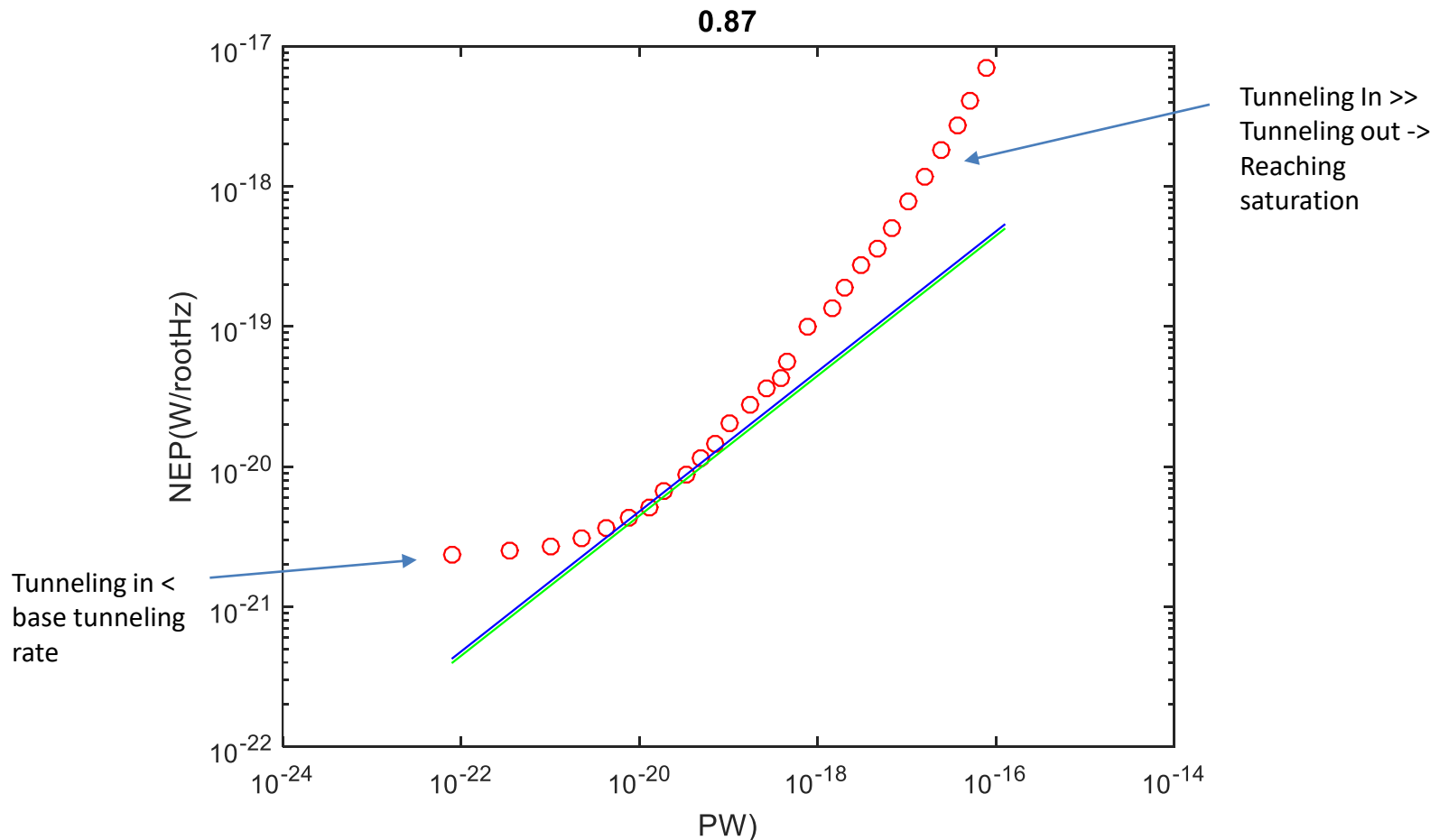
- NEP for various levels of optical illumination



- PSD time span 2s
- Gate sweep frequency 100Hz
- One sweep = 6 peaks
- QC peaks = 600Hz



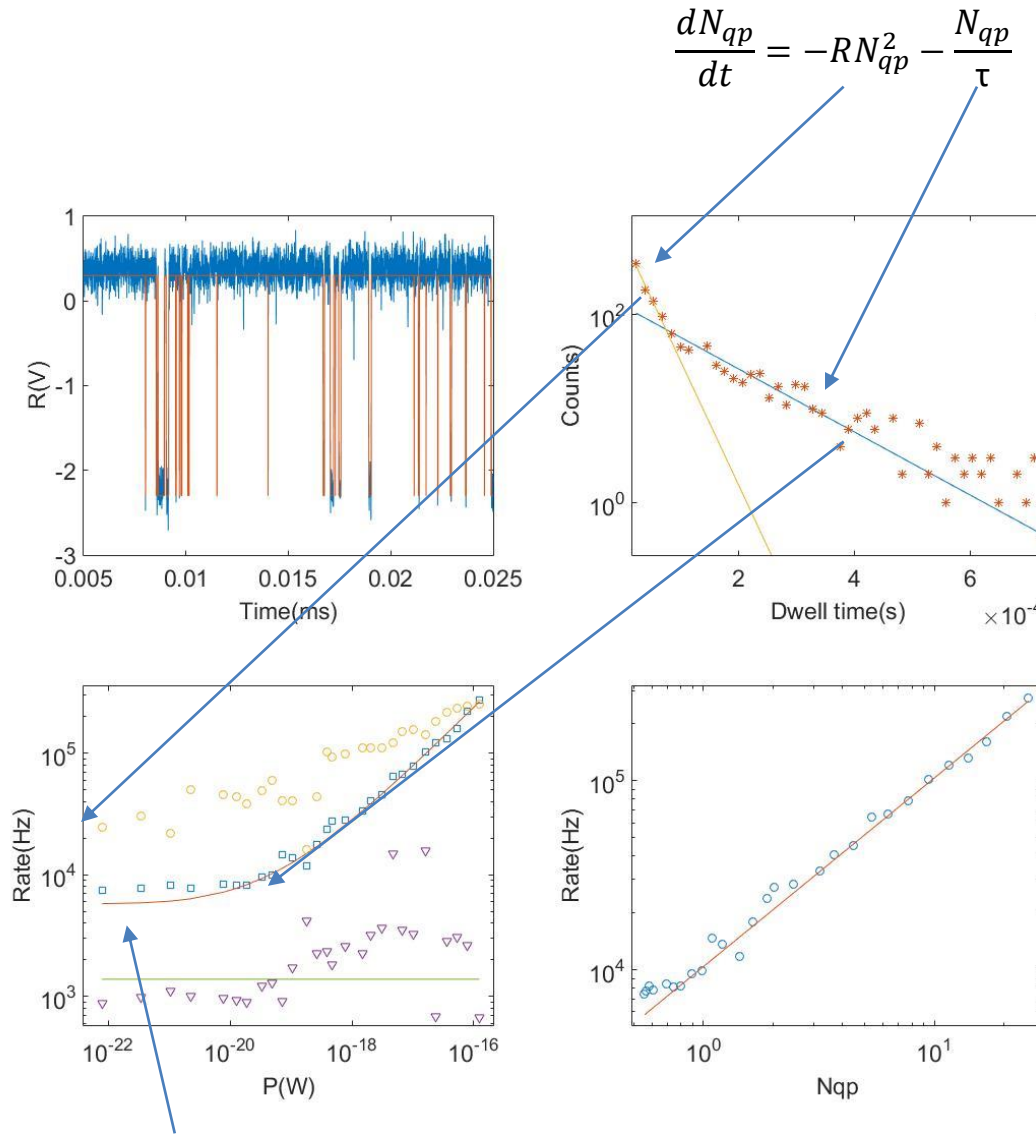
Lens coupled mesh absorber LEQCD



- $P^{1/2}$ dependence implies photon noise limited performance
- Efficiency extracted from ratio of measured NEP and photon shot noise NEP
- Should be able to detect single photons



Search for Single Photon Events – clues from DC biased time streams



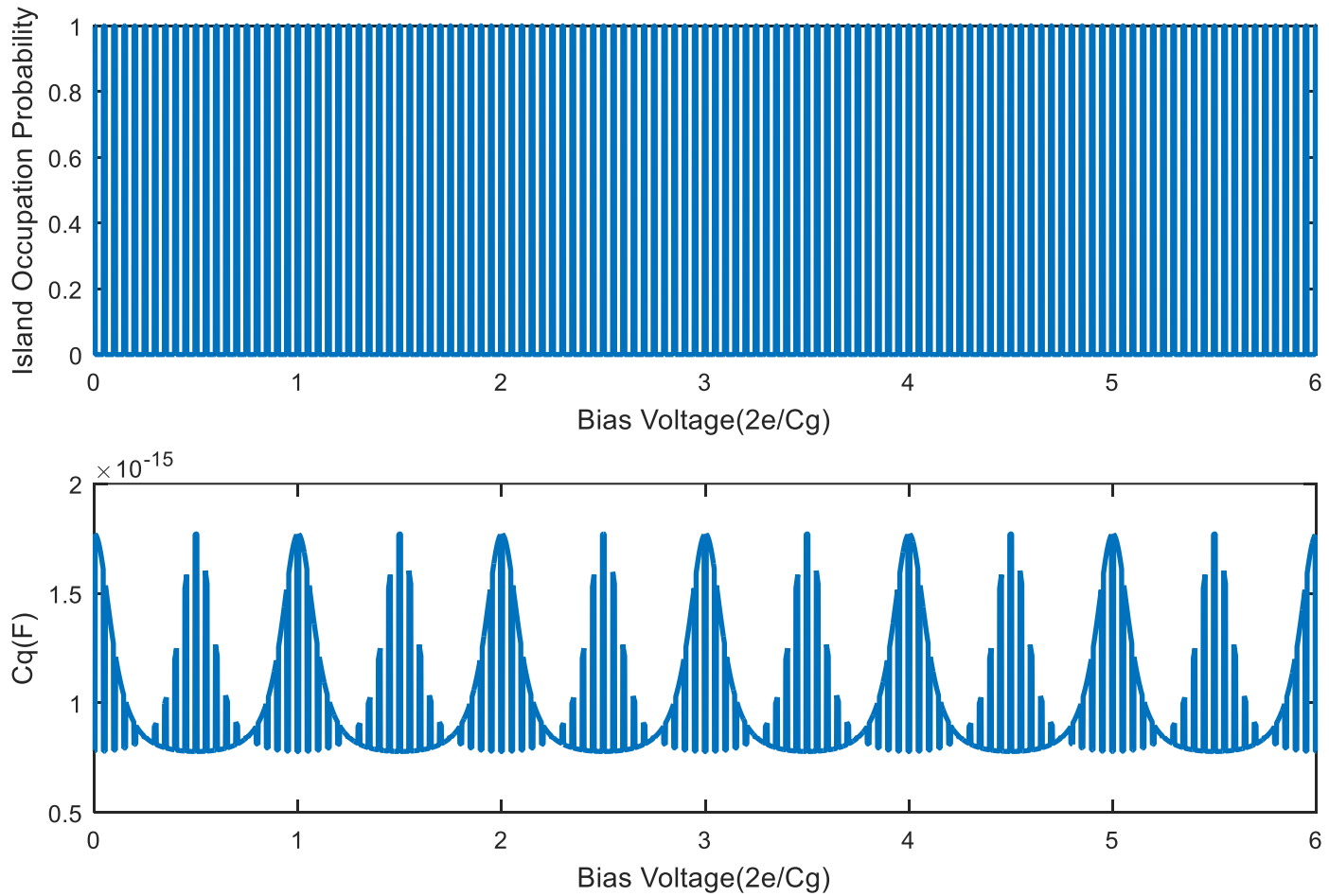
Background tunneling
rate $\sim 8\text{kHz}$

- Measure time trace while DC biased
- Obtain histogram of dwell times
- Fit histogram to exponential decay
- Rate for longer times is due to residual lifetime
- Faster rate at shorter times due to single photons
- Tried to look for those faster events in smaller chunks of time stream – DAQ rate not fast enough to get good signal to noise ratio
- Can estimate how fast the initial tunneling rates are from the measured tunneling rates versus number of quasiparticles
- One photon generates on average 20 quasiparticles \Rightarrow instantaneous rate about 220kHz



How to filter out background tunneling

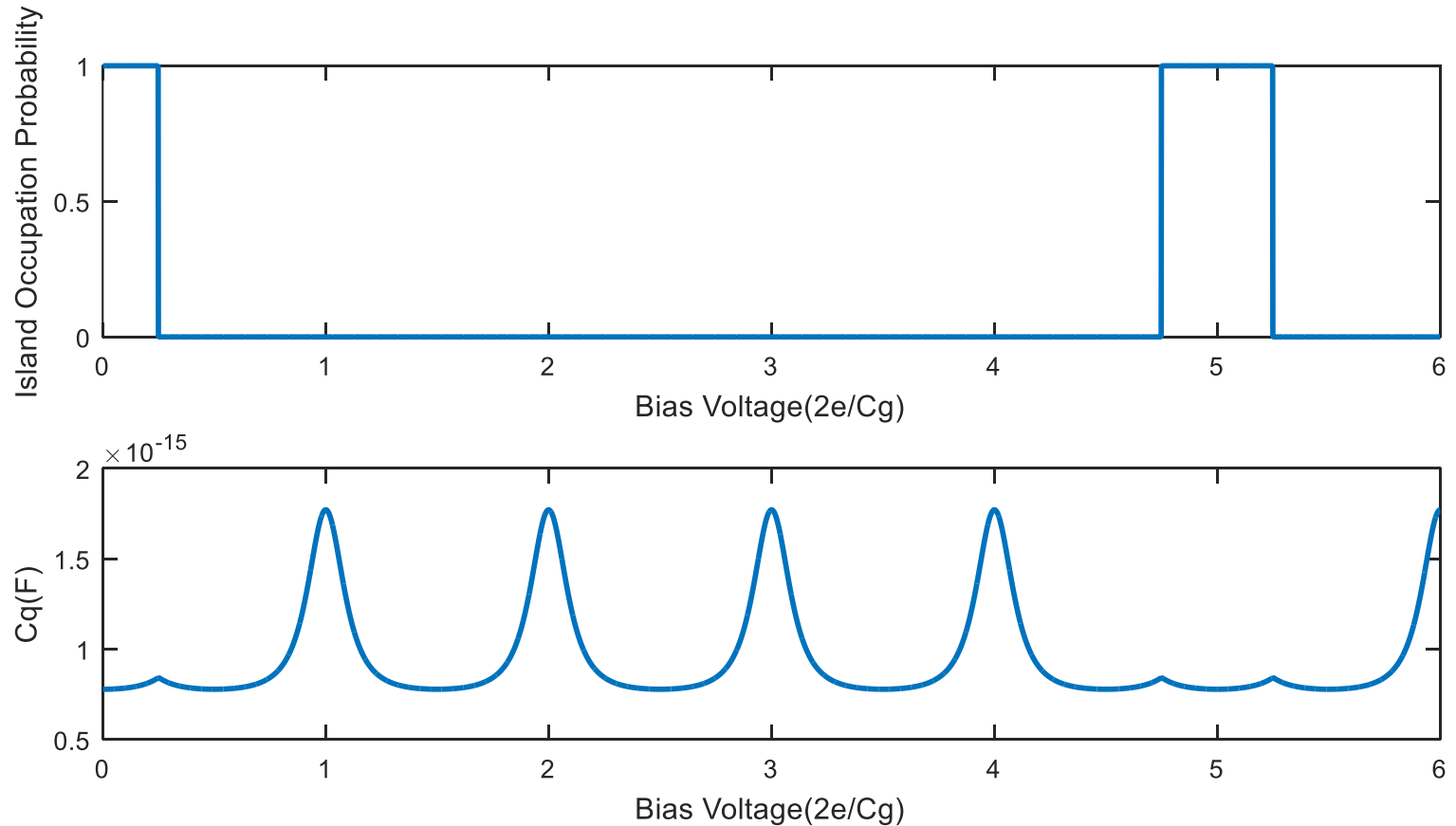
Gate sweep frequency \ll Tunneling in rate





How to filter out background tunneling

Gate sweep frequency > Tunneling in rate – effect of photon absorption

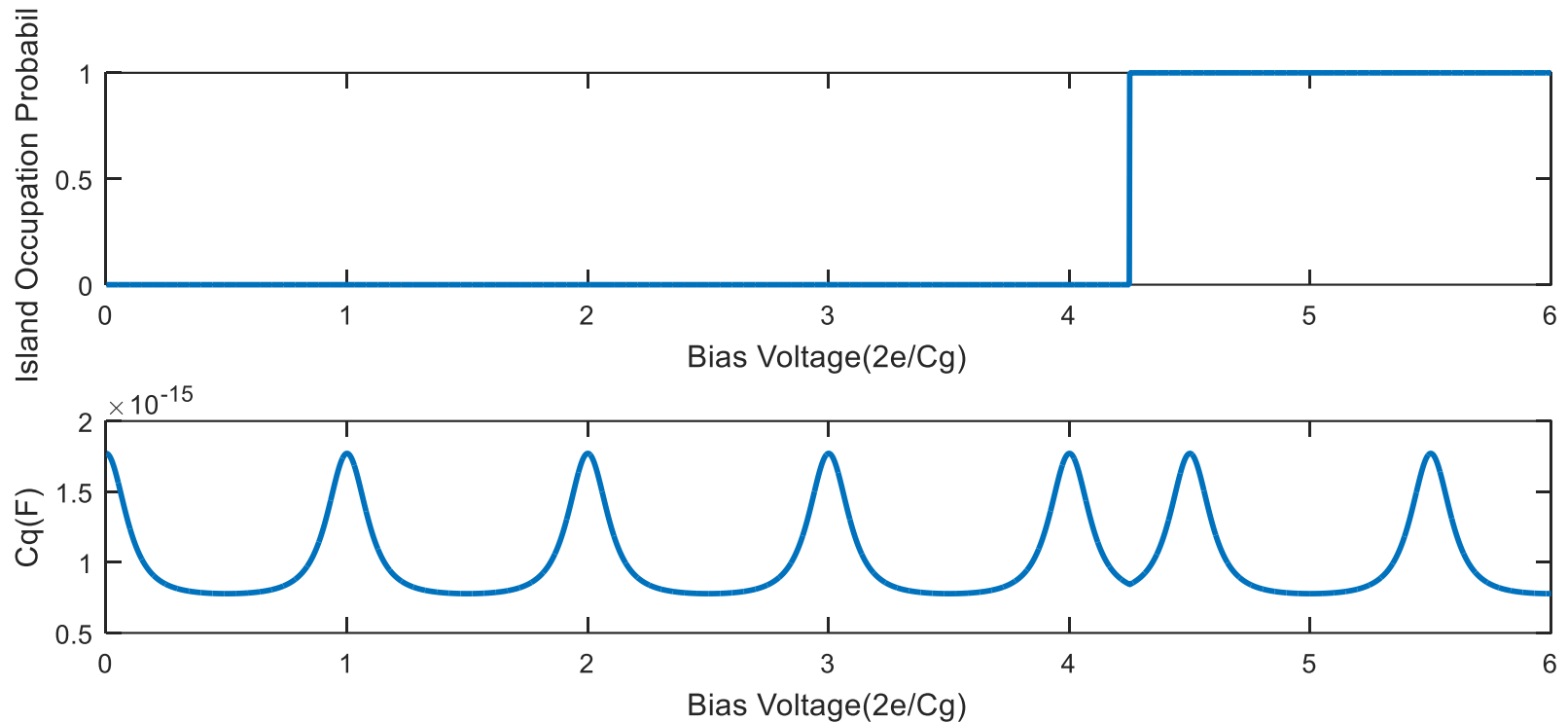




How to filter out background tunneling

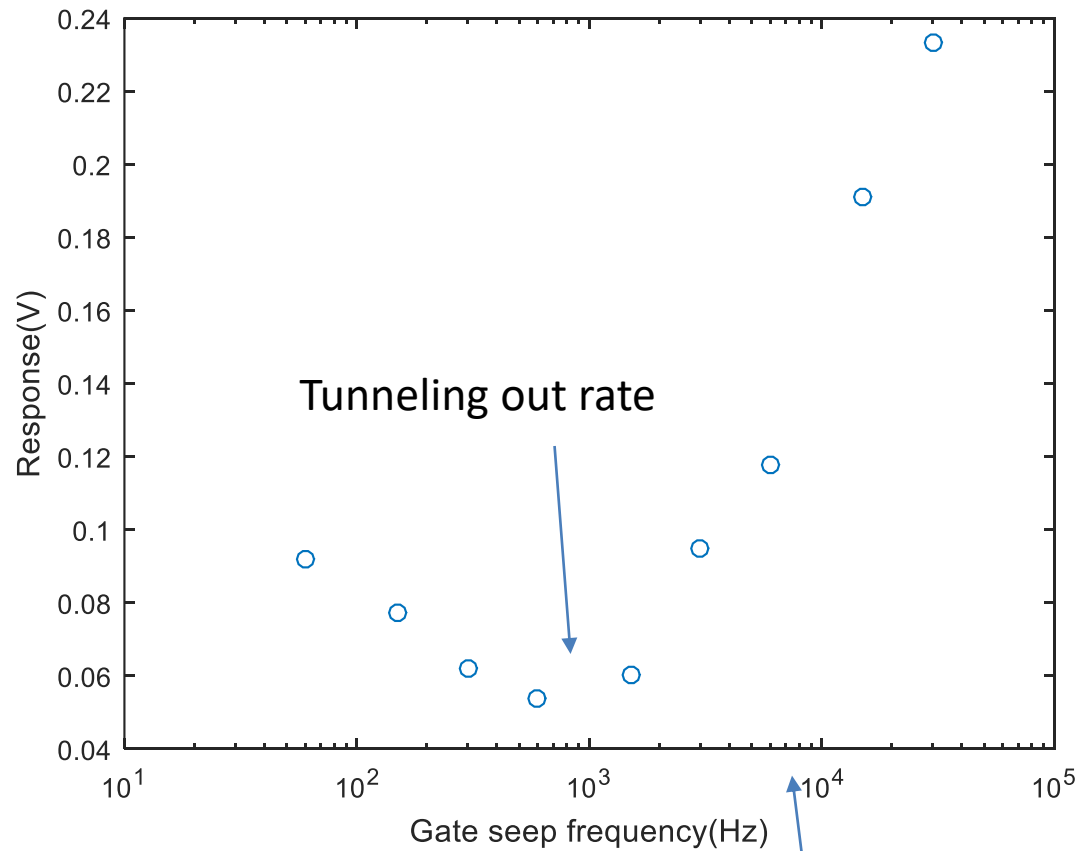


Gate sweep frequency > Tunneling in rate – effect of background tunneling = e-shifts





How to filter out background tunneling

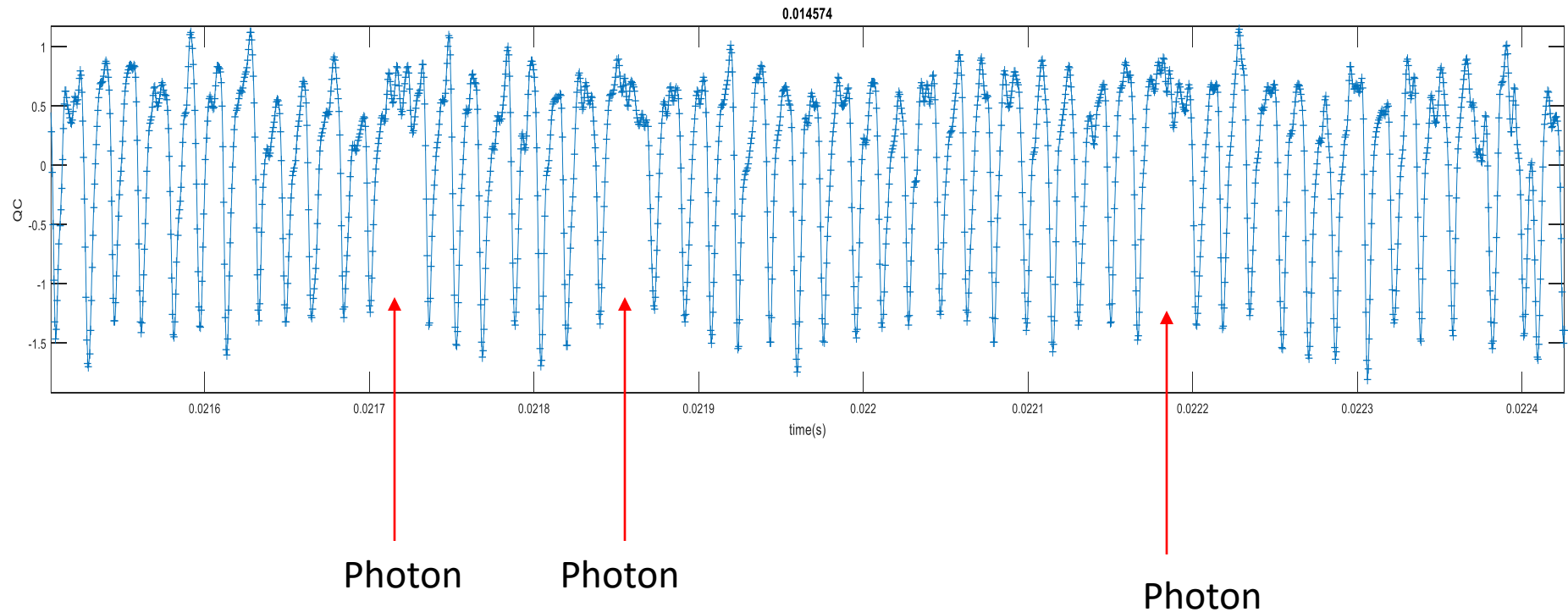


Background tunneling in
rate



“ Fast sweep reveals single photon events spoiling QC signal

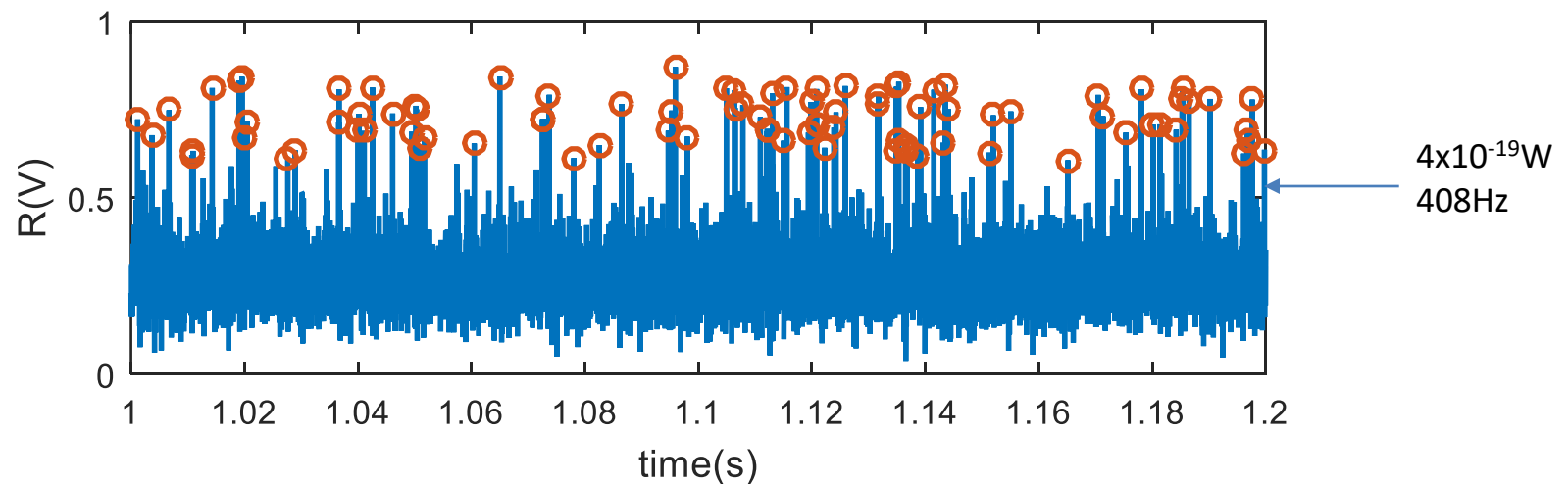
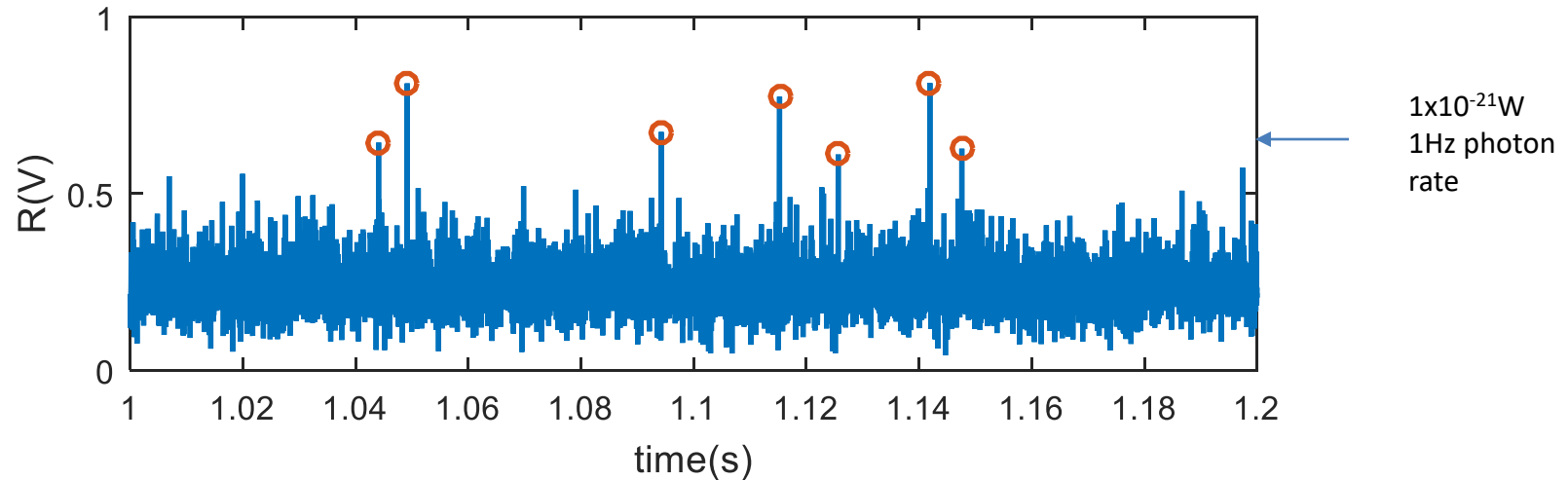
- Sweep rate $\sim 22\text{kHz}$ spanning 3 Quantum Capacitance Peaks \Rightarrow effective sweep rate $\sim 66\text{kHz}$
- Should block background tunneling while still allowing tunneling due to single photon absorption
- Raw QC time trace should be absolutely periodic
- Gaps are due to high tunneling suppressing the Quantum Capacitance signal
- Therefore Gaps should be due to single photon absorption





Variance evaluated in 30 us bins shows photon events

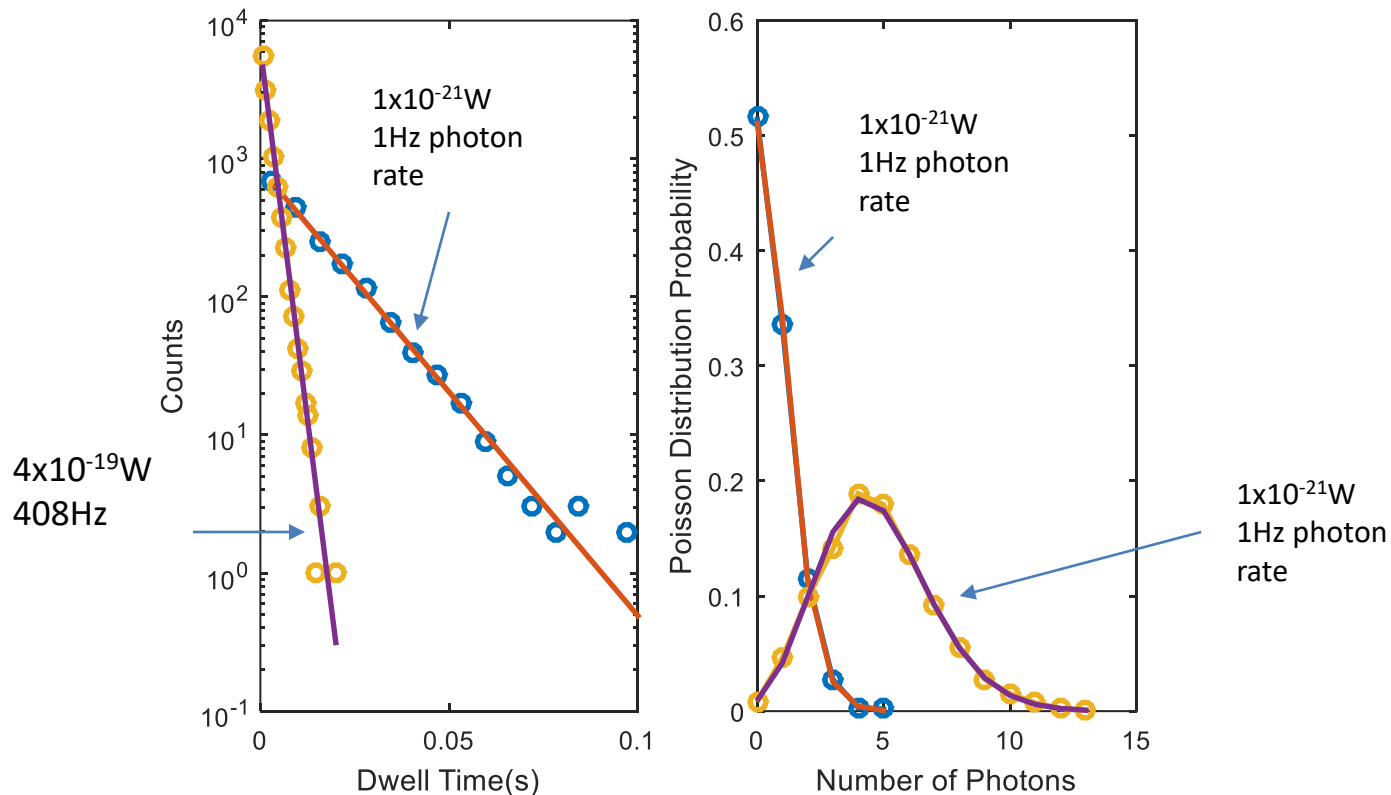
- From time traces calculated variance of slices corresponding to 2 QC peaks (to avoid problems at the edge of sweep with e-shifts) – slices are 30μs long
- Subtracted this trace from the maximum of the traces
- Gaps in the Quantum Capacitance trace will show up as peaks
- Repeat for different black body source temperatures





Photon arrival intervals follow Poisson statistics

- From the photon time traces, extract dwell time histograms – exponential decay corresponds to Poisson statistics
- Calculate probability of having N photons within a time interval 36ms (Arbitrarily picked)
- Plot probability x number of photons; blue circles is measured, lines are calculated Poisson distribution probability (no fit, just using measured average number of photons)



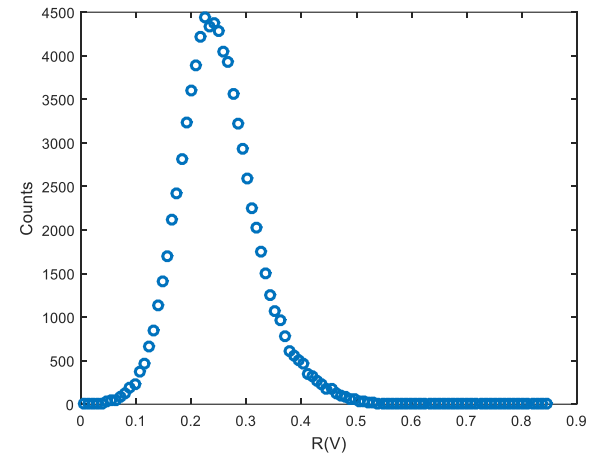


Photon arrival statistics

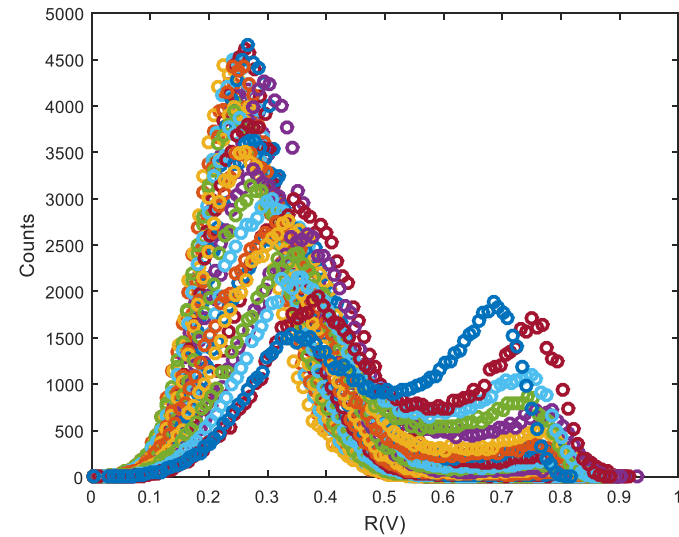
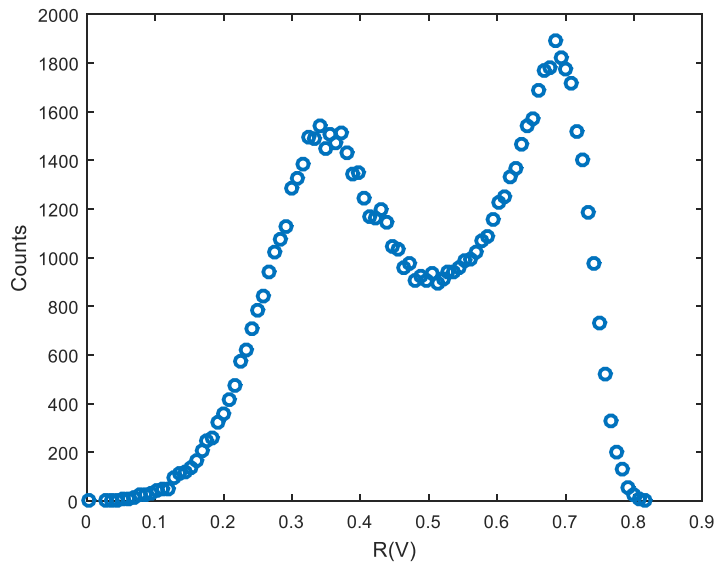


Histogram of response for various black body temperatures
For cold black body only peak around 0.25 exists
For hot black body peak around 0.6-0.7 is larger than peak at 0.25

Cold black body

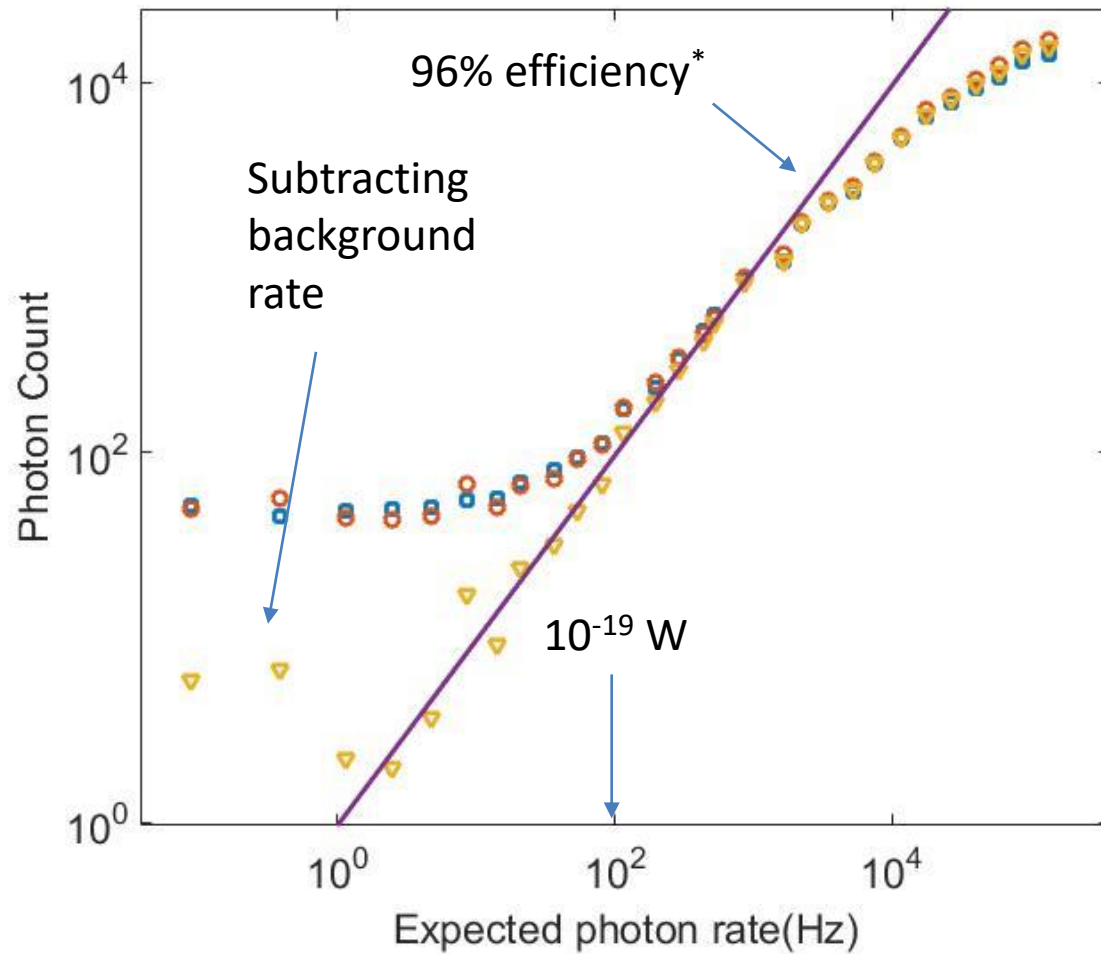


Hot black body



- Peaks get closer together at high black body temperatures due to filtering by the resonator of the high frequency stream
- Could lower resonator Q by stronger coupling at the expense of fewer channels

Counts of response between 0.6 and 0.9 versus number of expected photons



- Efficiency will decrease with when time intervals between photons become comparable to the time separation of two Quantum Capacitance Peaks

* With respect to absorbed power



Conclusion

- QCDs shot are noise limited at 10^{-19} W of optical loading
- Single Photon Counting at 1.5THz from 10^{-19} to 10^{-17} W demonstrated
- Large format arrays possible with frequency multiplexing
- Good candidate for a detector array in a cold far-IR spaceborne telescope

